To the Editor
of the Chemical Gazette
With the Author's compliments

ON THE

VENTILATION

OF

COAL MINES.

BY

WILLIAM BRUNTON,

M. INST. C.E.

LONDON:
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Fig. 1

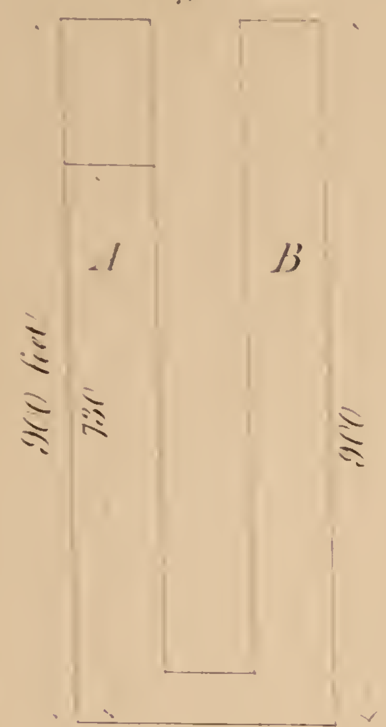


Fig. 2

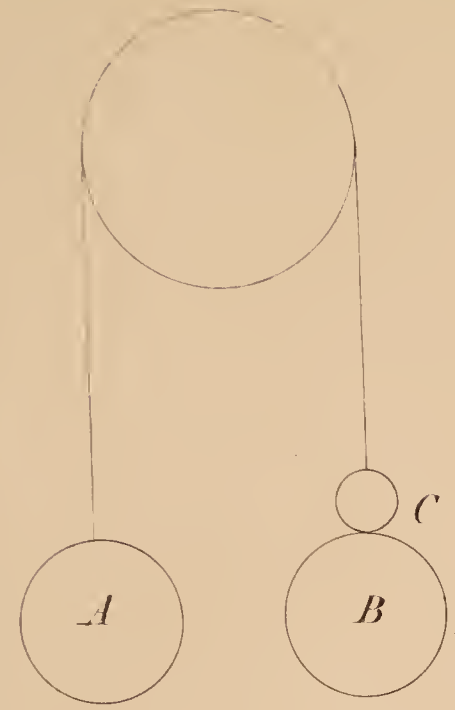


Fig. 4

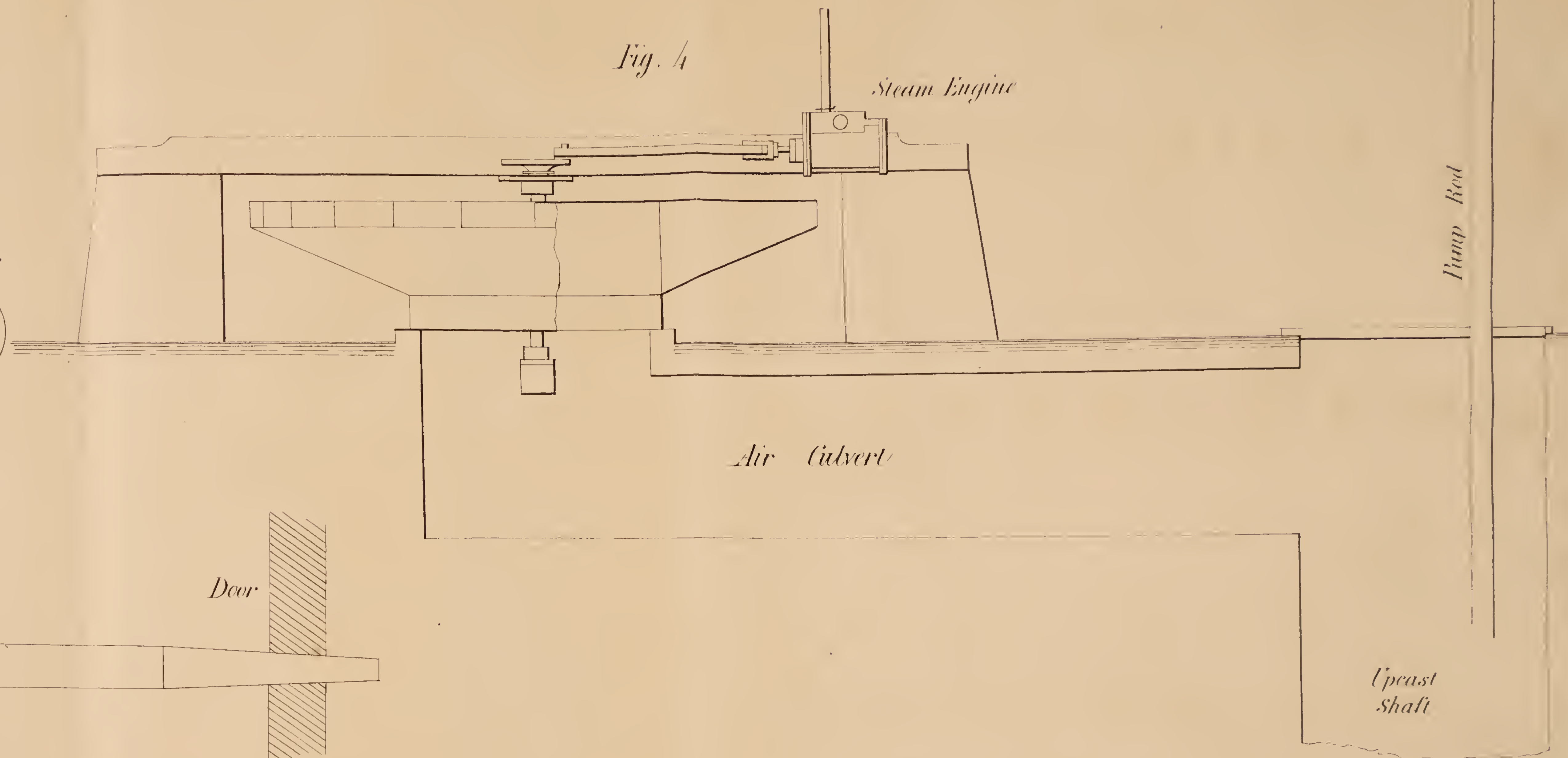


Fig. 3

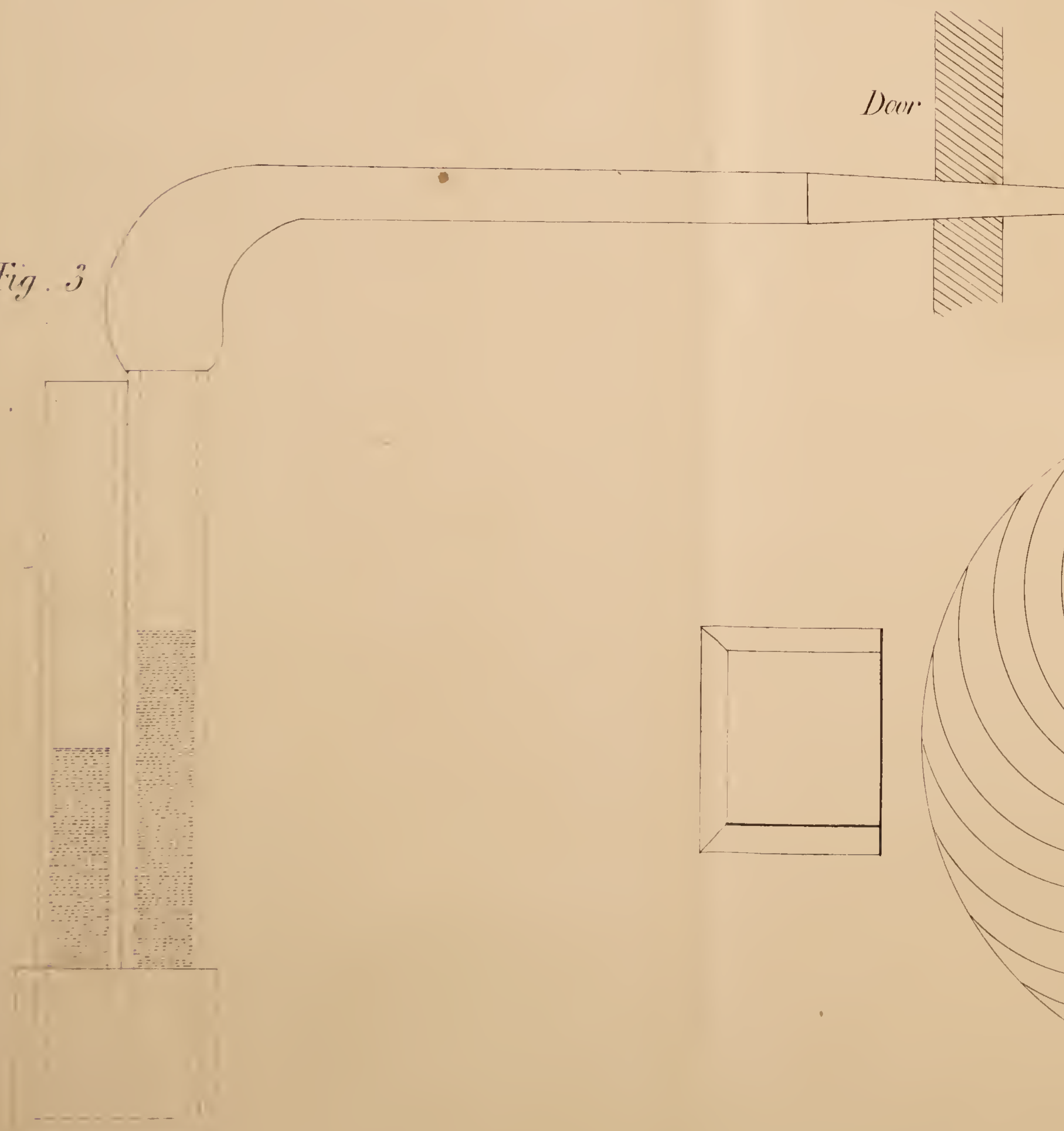
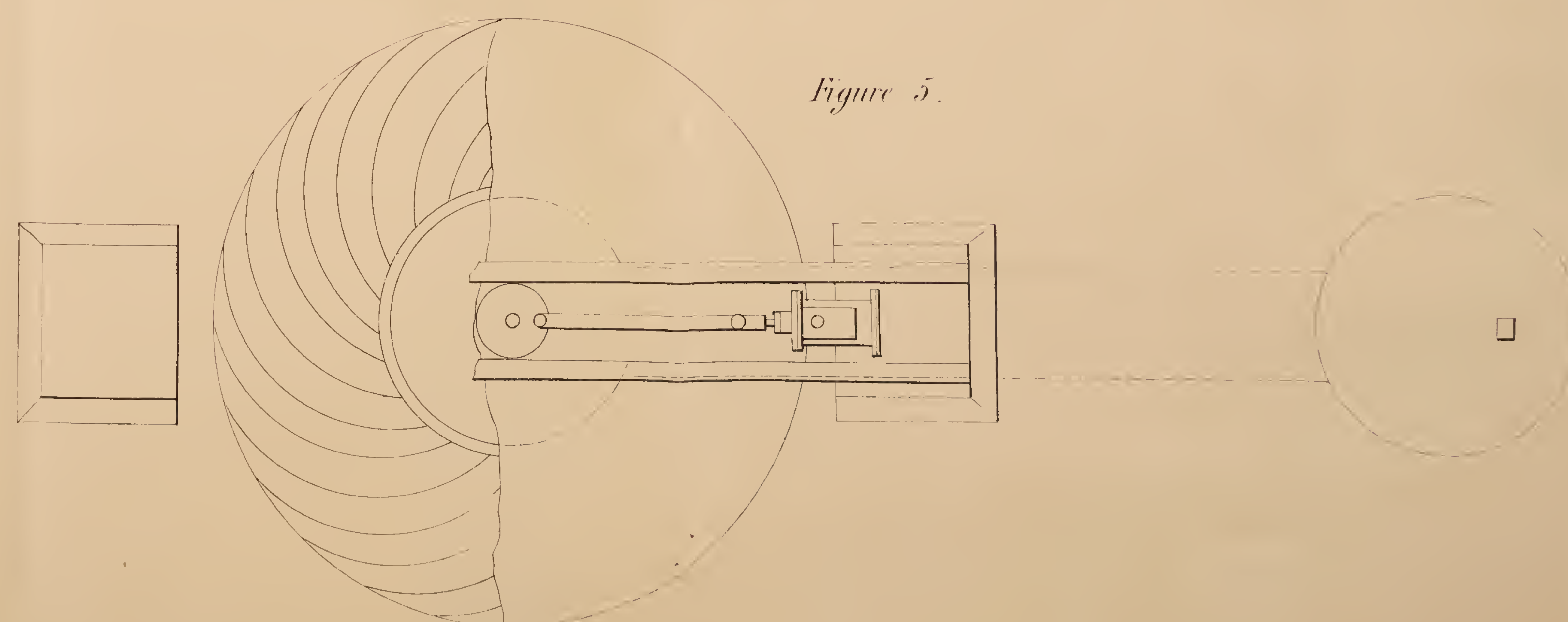


Figure 5.



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TO

THOMAS POWELL, ESQ.

OF THE GAER,

NEWPORT, MONMOUTHSHIRE,

Who, at a season of extraordinary depression in the Coal Trade, generously incurred the expense of erecting the first Exhausting Ventilator, with the view of testing its power of Rarefaction, and making it publicly known,

These pages are inscribed,

As a token of respect and gratitude, by

THE AUTHOR.

ON THE

VENTILATION OF COAL MINES.

The numerous instances of loss of life from the explosion of carburetted hydrogen in Coal Mines render an apology for any attempt to lessen or remove the evil unnecessary, while it is hoped that the elucidation of the subject, causing it to be better understood, will lead to the adoption of improved means of rarefaction, and in time obviate the necessity for the use of the safety lamp by the ordinary working Collier, which has been one of the most prolific causes of the appalling events alluded to. That scores of men for hours together should be breathing a highly explosive atmosphere, ready to ignite and destroy them in a moment upon the indiscretion of any one of the party with relation to his safety lamp, the principles of which he does not understand, or upon an accident befalling any one of these frail and fragile implements, is a condition of danger without a parallel.

In the following pages I propose to describe the ordinary means used to effect rarefaction of the air, so as to ventilate the works; to make some practical observations on the amount of power generated by these

means, and the effects of the ordinary application of them; to point out what appears to be the inherent defects of the principle of heat as a ventilator to a Coal Mine; and, lastly, to describe the apparatus which I invented, and erected for Thomas Powell, Esq. of the Gaer, near Newport, Monmouthshire, upon one of his Collieries, and which I can recommend as a mechanical substitute for the furnace, possessing much greater power of rarefaction, and in many respects better adapted to the varying circumstances of Coal Mines generally.

The ease and facility with which atmospheric air moves upon its receiving an increase of temperature is the principle upon which the ordinary method of ventilation is conducted.

In sinking a shaft, the heat communicated to the air in descending, and its contact with the bodies of the men, is usually sufficient to create an ascending and descending current for the supply of fresh air; and this is greatly promoted by a partition dividing the shaft into two compartments, the downcast on one side, the upcast on the other. The same thing is accomplished by sinking two contiguous shafts. But little progress can be made in working a Colliery till a more effectual means of ventilation is applied. For this purpose a furnace, or large open grate, is constructed near to the upcast-shaft, upon which a constant fire is maintained, over which the air passes, and is rarified in its progress from the workings of the Colliery to the upcast-shaft, when its buoyancy creates a draught through the ramifications of the Mine back to the downcast-shaft.

In order to judge of this mode of rarefaction, I have constructed a Table of easy application, showing the

expansion and weight of air at every 10 degrees of heat from freezing to 252 degrees; also a plain way of applying it to any particular case.

It must be evident that the ascension of air in the upcast is owing to its being volume for volume lighter than the air in the downcast, and that lightness is obtained by heating, and that the expansion consequent on heat is the true measure of its levity or tendency to rise.

The diagram fig. 1, represents two shafts of equal depth of 900 feet, A the downcast, B the upcast. Let us suppose the air in A 62 degrees, and the average heat in B 182 degrees. It will be sufficient for all practical purposes to carry out the calculation in perpendicular feet of one foot area, then we have (see Table)—

	Grains.	Grains.	
A, 900 cube feet at	518 =	466,200	
B, 900 ,, ,, ,,	420 =	378,000 ÷ 518	= 730
		88,200	

Shewing that 900 feet at 182 degrees is balanced by 730 feet at 62 degrees, as in the diagram, leaving 170 feet at 518 = 88,200 grains, or about 12·5*lbs.* on the square foot, as a gravitating power to propel the air upward in the shaft B.

But here it is necessary to observe, that in this hypothesis the air filling any short portion of the height of the upcast shaft is assumed to be of the same temperature throughout the whole of its area, so that the whole mass of heated air in the shaft moves as uniformly upward, as the air in the downcast shaft moves downward; but this condition is never attained in practice, for the air in passing over the fire is not

heated equably, but portions of it much hotter than others, whereby the elements of disorder are introduced, and as the current enters the upcast shaft, it does not diffuse itself horizontally through the area of the shaft as if it were a disc or piston, but, ascending with much rapidity on the side nearest to that by which it entered, causes frequently a descending current on the opposite side; and, though the air from the mouth of a deep shaft may discharge itself with apparent uniformity over the whole of its area, yet from what takes place at the bottom already referred to, and something of the same kind repeated upon the entrance of the foul air from the goafs, with other causes of retardation in the shaft itself, the effective temperature of the ascending air is not easily determined, always doubtful, and often leads to misapprehension as to the power, and supplies a strong proof of the superiority of the principle of traction over that of propulsion of aerial currents. Hence the desirableness that the avenues of a Colliery, or of any other extensive series of compartments subjected to ventilation, should be (with relation to the direction of the current) behind the power of rarefaction; that is, that the rarefying power will be better applied at the top of the upcast shaft than at the bottom; for then the entire ventilation is conducted on the principle of traction, avoiding the defects consequent on propulsion. To compare these two principles, a good illustration is afforded in the difference that is experienced between *drawing* and *pushing* a rope through a long passage. Besides, there is great advantage in having the means of rarefaction upon the surface; it is thereby out of the reach of an explosion, should such take place, and ready to restore a current through the works immedi-

ately after an explosion, to the probable saving of life, many having perished for want of such a supply.

I am aware of various rules that have been laid down for calculating the velocity and force with which the air ascends the upcast shaft; but I have never found them to tally with experience, but often imposing a notion of security where danger ought rather to have been apprehended.

This has induced me to investigate the subject, admitted on all hands to be an intricate one, and to submit the following hypothesis, which if correct may prevent the furnace as a power of rarefaction being rated beyond its capability, as it has been many times, to the fearful destruction of human life.

The principle upon which I think the velocity of the air in the two shafts A and B, acting alone and unconnected with the working of the Colliery, should be calculated, is analogous to two weights suspended by a line passing over a pully (supposed without friction), and the length of the line may represent the depth of the shafts. (See fig. 2.) Whilst the weights A and B are equal, there can be no motion, for they neutralize each other; but if a weight (C) is added to one of the weights A or B then motion will take place, but the added weight C will not descend as it would if it descended alone freely, for it cannot move without communicating an equal motion to the two weights A and B; an equal force must therefore be distributed through the three weights A, B, and C, and that force can only come from the gravitating force of the latter (C), this force being that with which it would actually descend if left to itself.

If A and B be each 10, and C = 1, then the mass

through which the force is diffused will be equal to 21 times the weight of C. The force actually existing in each portion of the mass is therefore the 21th part of what it was in each portion of the added weight C, and will in this combination descend with the 21th part of the velocity that it would do if it descended freely, that is, the 21th part of the ordinary effect of gravity.

Having thus endeavoured to explain the principle upon which I believe the furnace rarefaction proceeds, let us now return to the diagram, fig. 1.

Where 900 feet in B and 730 in A represent the weights A and B of fig. 2 balancing each other, and 170 the weight C with a fall of 900 feet, the velocity acquired thereby when falling freely is theoretically 240 feet per second; but 170 is the 10·6th part of 1800 (the sum of 900, 730, and 170), consequently 240 divided by 10·6 gives us 22·7 feet per second for the real velocity in the upcast shaft.

Thus we have an approximation at least to the velocity of the air in the two shafts; but which is after all of little practical use or application; for, the direct opening between the shaft being closed, the weight C 170 (which in the supposed case is equal to 12·5*lbs.* upon the square foot) immediately becomes a gravitating force descending with more or less velocity as it is enabled to propel the air through the workings of the Colliery; and, taking 12·5 as the first mover or cause, we may look for 9 as the mechanical effect in moving the air through all the air-courses of the Colliery, and ultimately discharging it through the upcast shaft into the atmosphere; and, though it is impracticable to balance the account by estimating the actual weight of air in the Colliery, the different velo-

cities with which it is propelled, together with the amount of retardations, which if obtained would accurately express the force applied, yet the aggregate may be satisfactorily ascertained by the application of the water gauge (fig. 3) to any single partition or door which stops the direct passage of the air between the shafts, and constrains it to take the circuit of the Colliery workings; that is, where the downcast and upcast shafts are contiguous, and one side of the door is directly and freely connected with the influent current from the bottom of the downcast, and the other side similarly connected with the effluent current as it enters the upcast, the difference of the height of the water in the tubes of the gauge will express the force applied to maintain the current between the bottom of the two shafts passing through the workings of the Colliery analogous to the amount of force required to draw a long rope through a winding passage.

We will now advert to some circumstances constituting the inherent defects of the system of rarefaction by heat. The air-courses of a Colliery are necessarily intricate, winding, and presenting many obstacles to the progress of the air; and the currents through the shorter avenues must be partly retarded in order to promote the currents through those of greater length; the direction and constant management of which demand the skill, discretion, and experience of the viewer and his assistants. Great changes in the state of ventilation are effected by atmospheric influence, such as the difference of temperature, as well as that indicated by the rise or fall of the barometer; for during the night the atmosphere may be at freezing, 32°, and during the day at 72°; and, supposing the heat of the

upcast shaft to be the same, viz. 182°, we shall have during the day a reduction of the rarefying power equal to 33 per cent. or $\frac{1}{3}$; and this may often be simultaneous with a rapid fall of the barometer, whereby the exudation of fire-damp is very much promoted, inducing a state of things in the direction of danger, without a visible cause, and over which there is in this mode of rarefaction very little or no control; for the same atmospheric change that tends to danger from the efflux of gas diminishes the power of the furnace to expel it. Yet, under these circumstances, the alternative is resorted to, viz. putting some of the workings upon short allowance of air, trusting for safety to the Davy lamp.

It is a special part of the late improvements made in the ventilation of Collieries subject to fire-damp that a portion of the air conducted through the fiery workings is not permitted to approach the furnace, but is carried by a distinct air-course into the upcast shaft sufficiently high or distant from the furnace to avoid explosion. This necessity supplies another proof of the inadaptation of fire as a ventilator in a fiery Colliery.

I here observe that the depth of the shaft and the heat of the upcast, which I have assumed in illustration of rarefaction by the furnace, are taken from the actual condition of some of the best conducted Collieries in the counties of Northumberland and Durham; and, in so doing, I exhibit the power of the furnace nearly or quite at a maximum. Its power applied to a Colliery of less depth estimated after the same manner is proportionally of diminished effect. In none of the pits in South Wales where the furnace is used have I found the rarefaction to ex-

ceed $\frac{4}{10}$ of an inch of water. The ventilation is so dependent upon the agitation created and kept up by the transit of waggons and horses through the Colliery during the day, while the men are at work, that in the absence of this bustle the whole atmosphere becomes stagnant, and too dangerous to be re-entered by the workmen in the morning, until the stalls have been explored by the aid of a Davy lamp and pronounced safe. This deficiency of power in the furnace when applied to shallow Collieries demonstrates the want of a more powerful, mechanical, and controlable means of rarefaction, possessing universality of adaptation.

The air, impregnated in its passage with all the exhalations of the Colliery, and then heated by the furnace, is found to be exceedingly corrosive and injurious to iron, more especially where there is moisture. This circumstance alone occasions great expense and much anxiety to the proprietors of Collieries, where iron tubbing in the shaft is continually exposed to this deteriorating influence.

I will now describe the mechanical means I have substituted, and the particular advantages it possesses over the furnace as a ventilator.

I construct over the upcast shaft, or over a chamber immediately connected therewith, a hollow drum, with curvilinear compartments, through which the air is discharged with that degree of force due to the velocity with which the drum revolves upon its axis. The diagram, fig. 5, represents a drum, 22 feet exterior diameter, with curvilinear compartments: 16 feet being their mean diameter, the centrifugal force at 120 revolutions per minute will be 39·25, which, multiplied by the weight of 6 cubic feet of air $= \frac{444}{1000}$ of a pound, will

give a pressure of 17·5 pounds on the square foot, as the amount of rarefaction produced in the interior of the drum, and consequently in the upcast shaft with which it is connected, which is much beyond what can be obtained by the furnace, yet greatly within the limits of the capability of this machine, as shewn below.

Figures 4 and 5 represent a plan and elevation of it, connected by a short tunnel with the pump shaft as the upcast closed at the top by a strong cover with a hole through which the pump rod works; the machine is driven by a steam-engine sufficiently powerful to increase the rarefaction to meet and overcome any sudden or extraordinary influx of carburetted hydrogen. The amount of rarefaction is governed by the speed of the engine, and is also under constant and visible inspection by a water or mercurial gauge: thus when the drum revolves

					lbs.		
60	times per	minute the	rarefaction	is	4·3	on square	foot.
90	"	"	"	"	9·7	"	"
120	"	"	"	"	17·3	"	"
150	"	"	"	"	27·0	"	"
180	"	"	"	"	39·0	"	"
210	"	"	"	"	53·0	"	"

In order better to understand the peculiar self-adaptation of this apparatus to all the circumstances that present themselves in the practice of ventilation of Collieries, let us suppose it altogether unconnected with any length of air-course, the air from the atmosphere having free access to the centre, and space for free discharge from the circumference, and a velocity given to it of 150 revolutions per minute, creating a rarefaction of 27 *lbs.* per square foot in the middle of the

drum; then the velocity of the air through the machine would be 108 feet per second, and the aggregate amounting to 8424 cubic feet per second, or 505·440 per minute.

Then let us suppose a state the very reverse of the above, viz. that no air be permitted to enter the drum at the centre part, of course none can be discharged at the circumference; therefore, there being no resistance to the motion of the drum from discharge of air through the curvilinear compartments, but the power of the engine continuing the same, is consequently expended in increasing the velocity of the drum, and thereby the rarefaction. In the former case the effect is exhibited in the discharge of air; in the latter by the degree of rarefaction maintained in the middle of the drum.

From consideration of these two cases, it is manifest that the power required to work the machine will be as the quantity of air ascending the upcast shaft, and the amount of rarefaction required to draw it through the Colliery; and such is the principle of self-adjustment of this apparatus, that if from any cause a less quantity of air is passed through the Colliery at one time than another, the engine (always exerting the same power) will of its own accord accelerate the velocity of the drum and increase the rarefaction, for, the power applied being the same, the effect will be commensurate in the quantity of air discharged, the amount of rarefaction attained, or both combined.

The machine is an entirely new modification of the fan. Its construction is of the most simple integral character; it has no valves or separate moving parts; has no attrition, and all the friction is resolved into a foot pivot moving in oil; when at rest offers no im-

pediment to air ascending from the shaft, is very inexpensive, and liable to no derangement ; in short, it is a simple mechanical implement, whereby any degree of rarefaction necessary to ventilation is rendered certain and regular, being subject to the law of central forces, which is as fixed and determinate as that by which a stone falls to the earth.

In contrasting it with the furnace, it may be further observed, that it is subject to no sensible difference upon the changes of the barometrical column, but, on the other hand, is capable by increase of velocity at such seasons of obviating or counteracting the danger connected therewith, and is equally applicable to all depths.

There will be no necessity for the separate conveyance of air by a stone drift into a higher part of the upcast shaft as practised to avoid the furnace.

All the injurious effect upon the iron in the upcast shaft will be entirely prevented, and no part of the workings need be stinted of air as to quantity.

By increasing the velocity of the machine during the absence of the workmen the stagnation and danger referred to in page 13 would be prevented.

But beyond the ordinary requirements of ventilation, as now practised, there is an advantageous application of this machine, which can in no respect be effected or imitated by the furnace. It possesses such power of rarefaction that the atmosphere of a Colliery may be subjected in half an hour to an artificial exhaustion of 3, 4, or 5 tenths of an inch of mercury, producing in the Colliery, during the absence of the workmen and their lights, the very same exudation of the gases that would have taken place during the natural change of the atmosphere indicated by a like fall of the barometrical

column; and before the men re-enter the Mine the machine will discharge the noxious gas by a current of fresh air more copious and effective than can be produced by any other means in use. All that is needful to effect this is, upon the retirement of the workmen and their lights, that the air be prevented entering the workings from the downcast shaft; the exhaustion alluded to will immediately commence, for, the quantity of air ascending the upcast shaft being decreased, the drum will be accelerated, and the whole extent of the workings will thus be subjected in a few minutes to the full measure of rarefaction obtained in the upcast shaft; upon the fresh air being permitted to enter, the Colliery will be found in a state of extraordinary purity of atmosphere, and freedom from the risk of explosion.

It is the concurrent testimony of all intelligent underground men that the fire-damp exudes copiously during the fall of the barometer, and also that during its rise the reverse takes place; the fissures that during the fall were discharging gas, now absorb or draw in atmospheric air; but the effects attendant upon a fall of the barometer must necessarily be more or less dangerous in proportion to the time it has been rising or nearly stationary, when a large portion of the gas evolved during that period will have accumulated in the goaf basins or vaults. The nature of this is so well described in the Report of Messrs. Lyell and Faraday upon the explosion at the Haswell Colliery in 1844, that I have requested and obtained permission to make the following extracts; but the whole of that document deserves the attentive perusal of every coal miner.

"The goaf may be considered as a heap of rocky fragments rising up into the vault or cavity from which it has fallen, perhaps nearly compact in the parts which

are the oldest, lowest, and nearest the middle, but open in structure towards and near its surface, whether at the centre of the goaf or at the edges; and the vault or concavity of the goaf may be considered as an inverted basin, having its edge coincident with the roof of the mine all round the goaf.

"Let us now consider this goaf as a receptacle for gas, or fire-damp, a compound of hydrogen and carbon, known as light hydrocarbonate, and by other names. The weight of pure fire-damp is little more than half that of air; it gradually and spontaneously mixes with air, and the weight of any mixture is proportionate to the quantities of air and fire-damp. Any gas that may be evolved in the goaf, or that may gradually creep into it along the roof of the workings, against which it will naturally flow, will ascend into the goaf vault, and will find its place higher in proportion to its freedom from air; and this will go on continually, the goaf vault forming the natural basin into which all gas will drain (upwards) from parts inclining to the goaf, just as the concavity on the side of a gentle hill will receive water draining downwards from its sides, and from the parts above inclining towards it.

"Thus goafs are evidently in mines subject more or less to fire-damp, reservoirs of the gas, and explosive mixtures; giving out their gas into the workings of the mines by a gradual underflow in smaller or larger quantities under ordinary circumstances, or suddenly, and in great proportion, on extraordinary occasions; and they may either supply that explosive mixture which first takes fire, or they may add their magazine of fire-damp and explosive mixtures to increase the conflagration when the fire reaches them from an explosion in some other parts of the mine.

"There is one other point connected with what may be called the action of the goaf, and the occasional, sudden, and temporary discharge of gas from it. One of the witnesses on the inquest, Mr. G. Hunter, pointed out the effect he had observed in the mine on a change in the barometer,—that as the barometer fell fire-damp would tend to appear, and that it did this the more suddenly and abundantly if the barometer, having continued high for some time, fell suddenly; and Mr. Buddle has already strongly stated his opinion that accidents from fire-damp always occur with a low barometer.

"A fall of an inch in barometer, of a sudden, is rare, but a fall of one-tenth of an inch is not, and that in such a goaf as the one supposed, viz. 13 acres, would place 7,550 cubic feet below the edge of the cavity; this all tends to issue forth at one place, and that generally a place where the ventilation is weakest. Hence it does appear to us that the goaf, in connection with barometer changes, may in certain mines be productive of sudden evolutions of fire-damp and explosive mixtures, and that the indication of the barometer, and the consequent condition of the mine, ought to be very carefully attended to."

From these observations it is obvious that if the fire-damp be drawn off at short intervals, as at every twenty-four hours, the accumulation and consequent danger will be very little compared with what it frequently is through the continuance of weeks of fine weather; and the daily discharge of these minor accumulations will maintain the Colliery, whilst the men are at work, in that state of safety (but better ascertained) experienced whilst the barometer is rising.

Possessing thus the power of anticipating the sudden

exudation of gas by drawing it off when it can do no harm, and of rendering the Colliery much more safe and healthful for the workmen, may we not reasonably hope that the subject will receive the attention it deserves, and that a system of alternate exhaustion and restoration will be judiciously brought into practice as experience will dictate, until the Davy lamp is no longer necessary for the common collier, the danger of explosion almost or altogether obviated, and the health of the miner greatly promoted.

It forms no part of my intention in this paper to enter the province of the viewer; yet, during a long period of professional engagements in applying machinery to mining purposes, I have had much opportunity of observation upon the practice and usages in different districts, and can testify and record the courage, perseverance, and scientific skill of some of the gentlemen now practising in this dangerous field of professional engagement, and also of many whose labours are ended, honourably embalmed in the records of the Coal trade, and whose names will be long held in high estimation.

To the viewers of Northumberland and Durham, we stand indebted for the present admirable means of conducting the air through the Collieries, wherein the principal feature is the division of the currents, reducing the velocity, but greatly augmenting the amount of disposable air. This has to many the appearance of a paradox; but, knowing many places where this practice would greatly improve their ventilation, I take this opportunity of recommending it, and, to illustrate the principle, I have constructed a Table (No. 2) of velocities useful in Colliery practice, with the force due to them in pounds per square foot, and the equivalent force in

pounds falling one foot per minute. Also No. 3, a short illustrative Table of equivalent effects, by which it will be seen that the same power needful to effect a current of 10 feet per second through a mile would effect a current of two feet per second 25 miles, carrying five times the quantity of air in the same time.

In imitation of our Cornish method of estimating the lifting of water from the Mines, I have in Table No. 2 denominated the power necessary to propel the air by pounds falling one foot per minute; but in the use of this table it must be borne in mind that the pressure per square foot is that due to the velocity, and, to produce this current, an increase of 25 or 30 per cent. must be made, as in ordinary mechanical operations, where 100 may represent the power or cause and 72 the effect.

The importance of watching the alternations of the barometer with relation to the ventilation of Coal Mines has been universally admitted; but the ordinary construction of that instrument is so ill suited to underground use, and the observation of pitmen, that the subject has hitherto had very little attention. This has induced me to contrive a barometer of more robust character, portable, and suited to the circumstances of a coal mine, yet so sensitive as to move with a gust of wind.

TABLE No. I.

Effect of Heat on the Expansion and Weight of Atmospheric Air.

Degrees of heat.	Weight of a cubic foot in grains.	Volume.
Freezing 32	550	100
42	549	102
52	529	104
62	518	106
72	506	109
82	495	111
92	487	113
102	479	115
112	470	117
122	461	119
132	453	121
142	446	123
152	439	125
162	432	127
172	426	129
182	420	131
192	413	133
202	407	135
212	401	137
222	394	139
232	386	142
242	381	144
252	376	146

TABLE No. II.

Pressure of Aerial Currents and Force expended.

Velocity in feet per second.	Pressure in lbs. per square foot.	Pressure per minute in pounds falling 1 foot.
1·0	·0022	0·13
2·0	·0092	1·10
3	·0206	3·70
4	·0365	8·64
5	·0570	17·1
6	·0822	29·5
7	·1120	47·0
8	·1465	70·0
9	·1850	99·9
10	·2280	136·8
11	·2770	178·2
12	·329	236·2
13	·385	300·3
14	·447	375·4
15	·513	461·7
16	·583	559·6
17	·661	674·2
18	·740	799·2
19	·825	940·5
20	·935	1122·0
22	1·11	1465·2
24	1·32	1790·8
25	1·49	2255·0

TABLE No. III.

The power necessary to propel a current of air at a velocity of 10 feet per second 1 mile, is equivalent to propel at a

,,	9	,,	1·25 with increased quantity of air			1·14 times
,,	8	,,	1·50	,,	,,	1·21
,,	7	,,	2·10	,,	,,	1·45
,,	6	,,	2·80	,,	,,	1·68
,,	5	,,	4·0	,,	,,	2·00
,,	4	,,	6·3	,,	,,	2·5
,,	3	,,	11·5	,,	,,	3·4
,,	2	,,	25·0	,,	,,	5·0

J. B. Nichols and Son, Printers, 25, Parliament-street, Westminster.